Extragalactic Distance Scale

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Technical details

Lectures on Thursdays at 14:00 with possible modifications

Test 35-40 questions.

Slides are not public !

Literature will be (sporadically) given during the course.

What is the main purpose ???

12-14 lectures

Introduction and historial context

Various observational effects (extinction, refraction, noise, etc)

Some observing techniques (photometry, IR, spectroscopy)

Parallaxes (from Besel to Gaia)

Standard candles CMD features: red clump, TRGB etc

Standard candles: pulsating stars P-L relations

Pulsating stars Baade-Wesseling method

Binary stars (astrometric, eclipsing)

Pulsating stars in eclipsing binaries

Long-range indicators (SN Ia, TF, BF, etc)

Other methods: quasars

PLANCK data and gravitational waves

Since ancient observations to present day astrophysics, distance determination has been one of the most important, fascinating and challenging goals in astronomy.

Knowing distances is much more than just knowing the scale; it also means knowing the physical nature of objects in the universe, and each significant improvement in the accuracy of the distance scale opens whole new fields of astrophysical research.

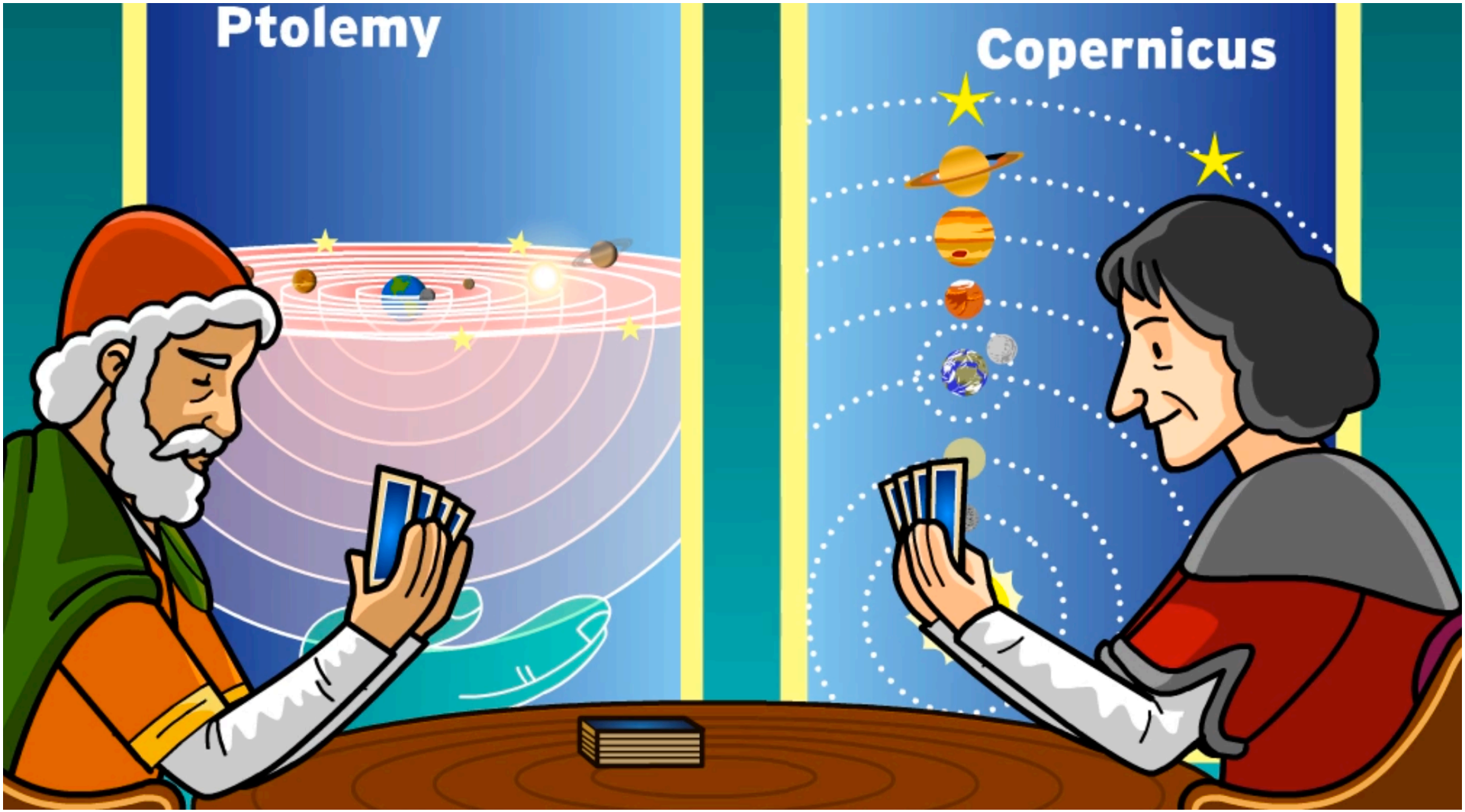
POSIDONII

DELINEATA A P. BERTIO *Christianissimi Regis* LVDOVICI XIII.
Geographo & Professore.

DIONYSIVS EN TH OIKOYMENHΣ ΠΕΡΙΗΓΗΣΕΙ

Πᾶ Ϲα χθὼν, ἁτε νῆϐος ἀπειρίτος, ἐϲεφάνωϲαι Εὐρυτέρη ϐεϐαυῖα πρὸς Ἠελίοιο κελεύθους
Οὐ μιὼ πᾶϲα διαπρὸ περίδρομος, ἀλλὰ διαμφὶς ΣΦΕΝΔΟΝΗ εἰκυῖα

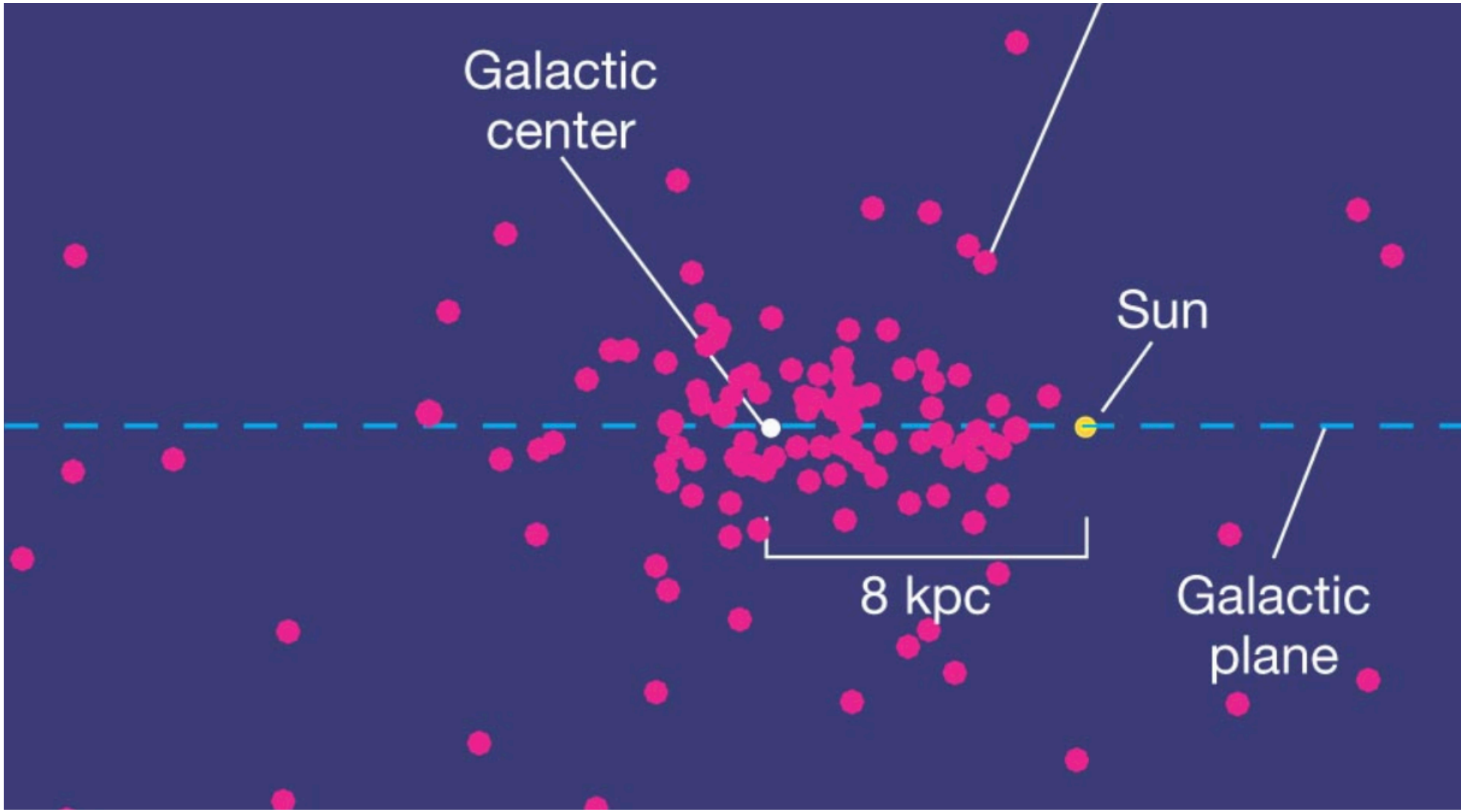
Cælauit LVTETIAE PARISIOR.


Ptolemy
Copernicus

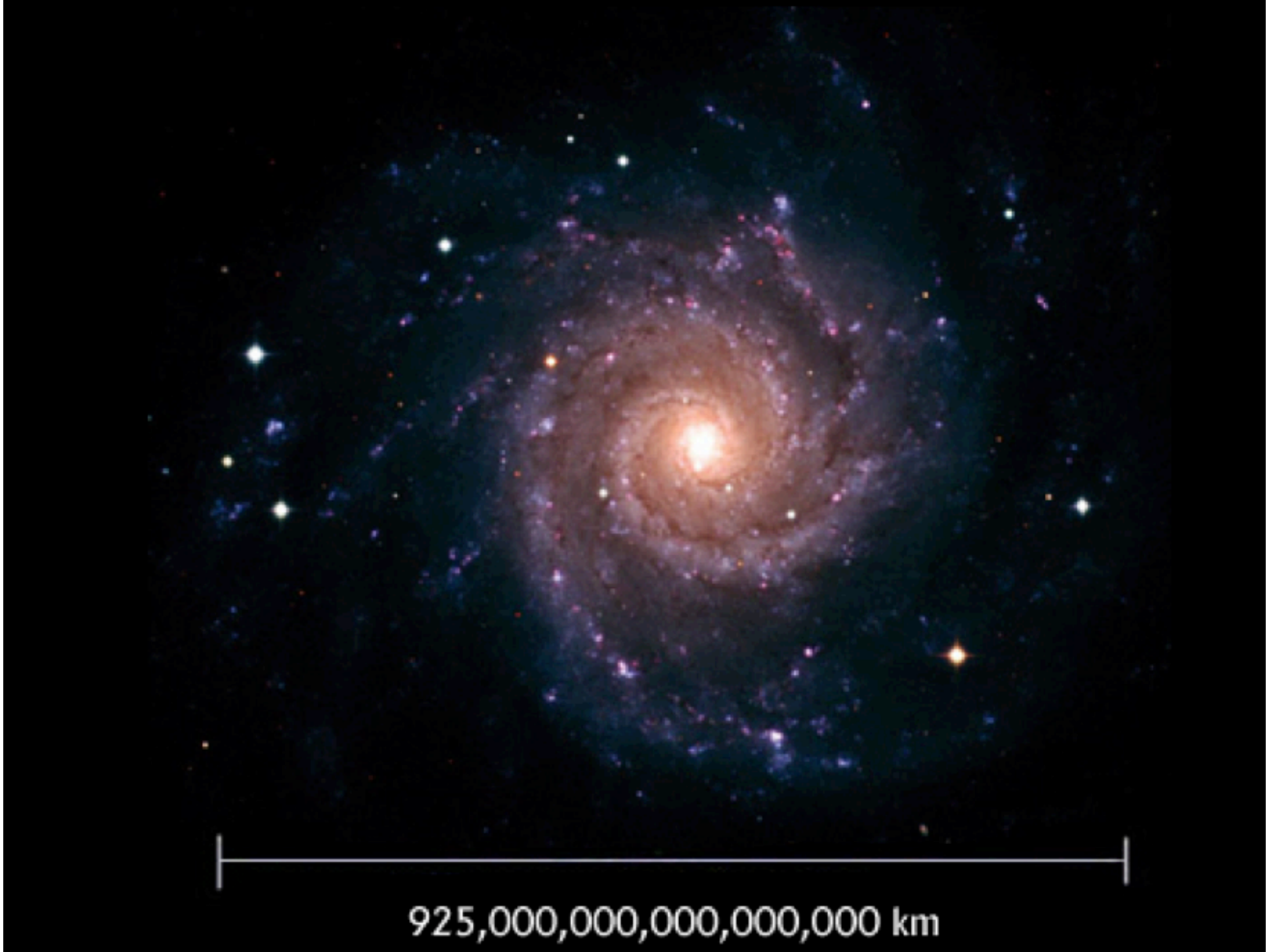
The arquitecture of the Galaxy

- Hershel XVIII counting stars in 3400 fields with 46 cm telescope
- Kepteyn beginning of XX w. 206 uniformly distributed fields
- Conclusion: density of stars decrese with increasing distance from Sun. MW size is close to 20 000 light years ..

Distribution of GC (Shapley 1917)



The Milky Way Galaxy




Apostolos Kechagias

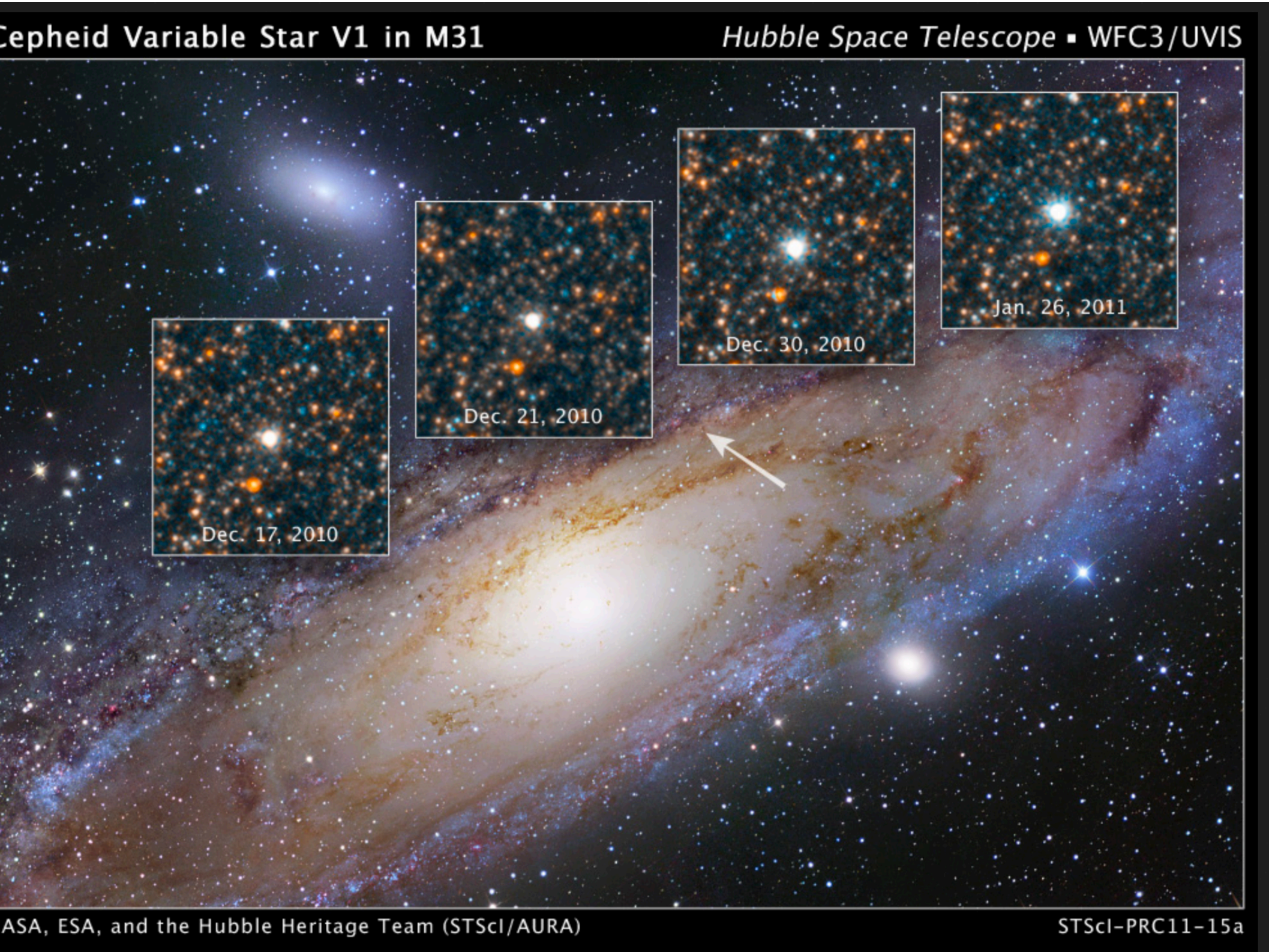
The great debate !

Smithsonian Museum of Natural History 26 April 1920

Debate on the nature of spiral nebulae and size of the Universe

Harlow Shapley: nebulae are part of the Milky Way

Heber Curtis: they are independent galaxies


Cepheid Variable Star V1 in M31
Hubble Space Telescope ▪ WFC3/UVIS
Dec. 17, 2010
Dec. 21, 2010
Dec. 30, 2010
Jan. 26, 2011
ASA, ESA, and the Hubble Heritage Team (STScI/AURA)
STScI-PRC11-15a

GRB: The Paczynski - Lamb Debate in 1995

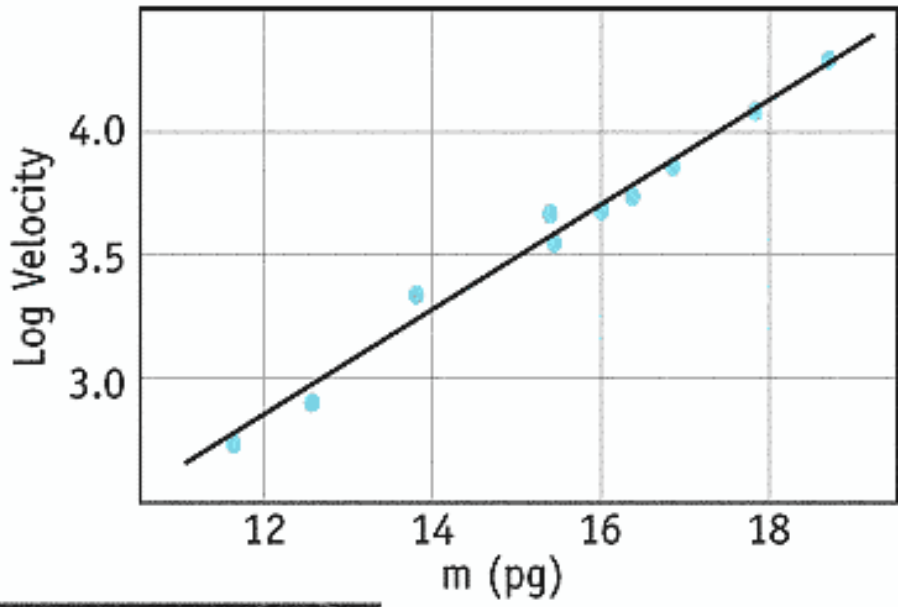
Donald Lamb argued that the GRB sources were in the galactic halo

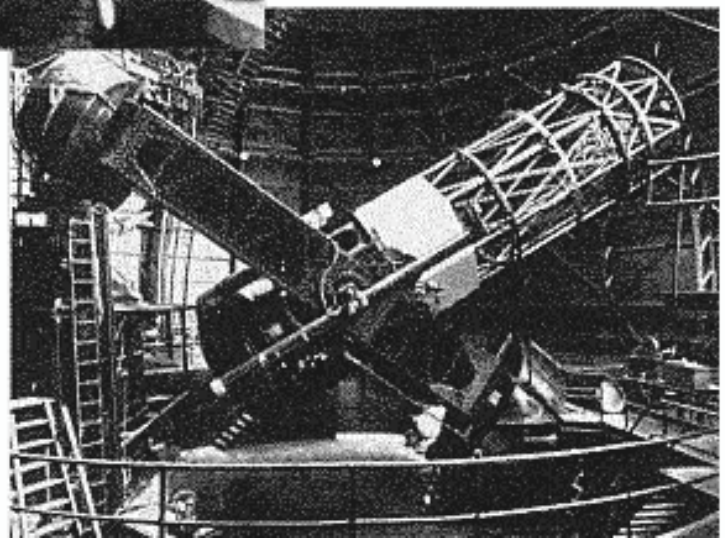
while Bohdan Paczynski argued that they were at cosmological distances

Hubble Law

Vr = Ho * d

Edwin Hubble





Mt. Wilson
100 Inch
Telescope

Short history on H_0

First determinations,

Georges Lemaitre (1927)

Robertson (1929)

Hubble (1929)

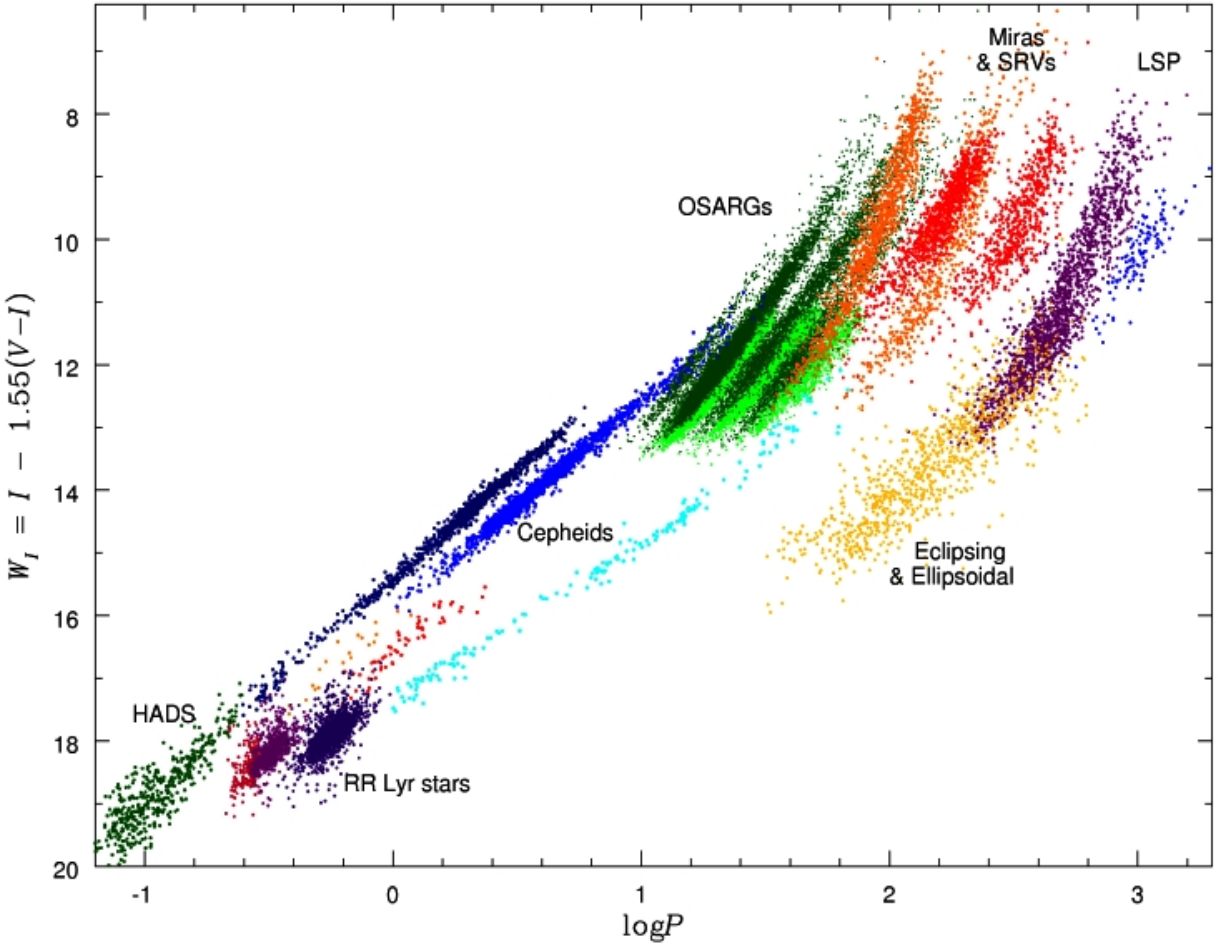
were close to **500 km/s/Mpc**.

Such a large expansion rate would imply an age of our Universe of 2 Gyr only !!!

Why it was a problem ???

First big revision

Walter Baade: Type II Cepheids !



Further corrections and ... at the beginning of **1960's** the widely accepted value of H_0 was **100 km/s/Mpc**

Long lasting controversy

Sandage and Tammann (1975) obtained much smaller values of H_0 around 55 km/s/Mpc,

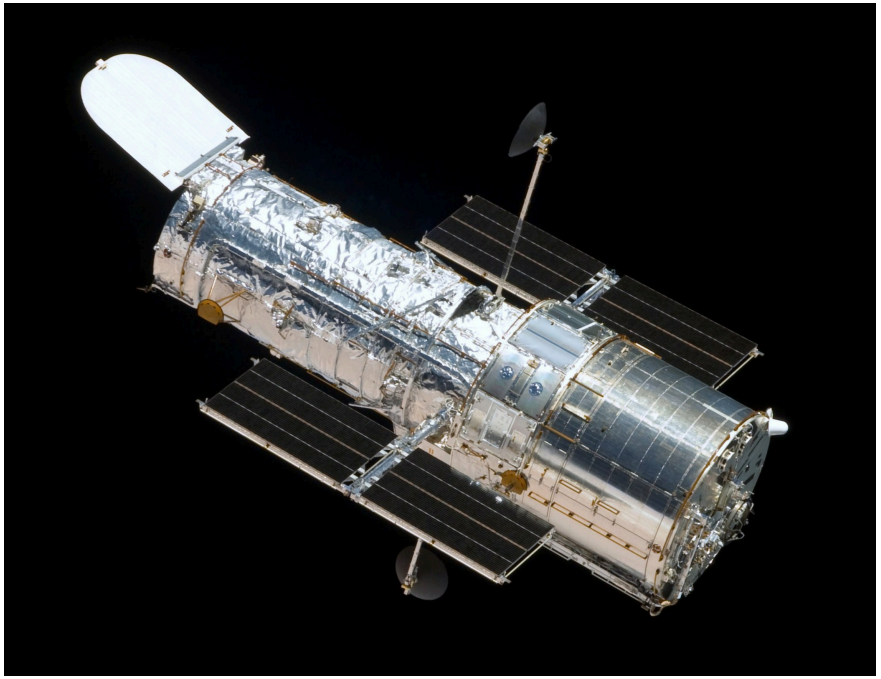
while the other important group working on a H_0 determination led by Gerard de Vaucouleurs (1978) continued to obtain a value close to 100 km/s/Mpc.

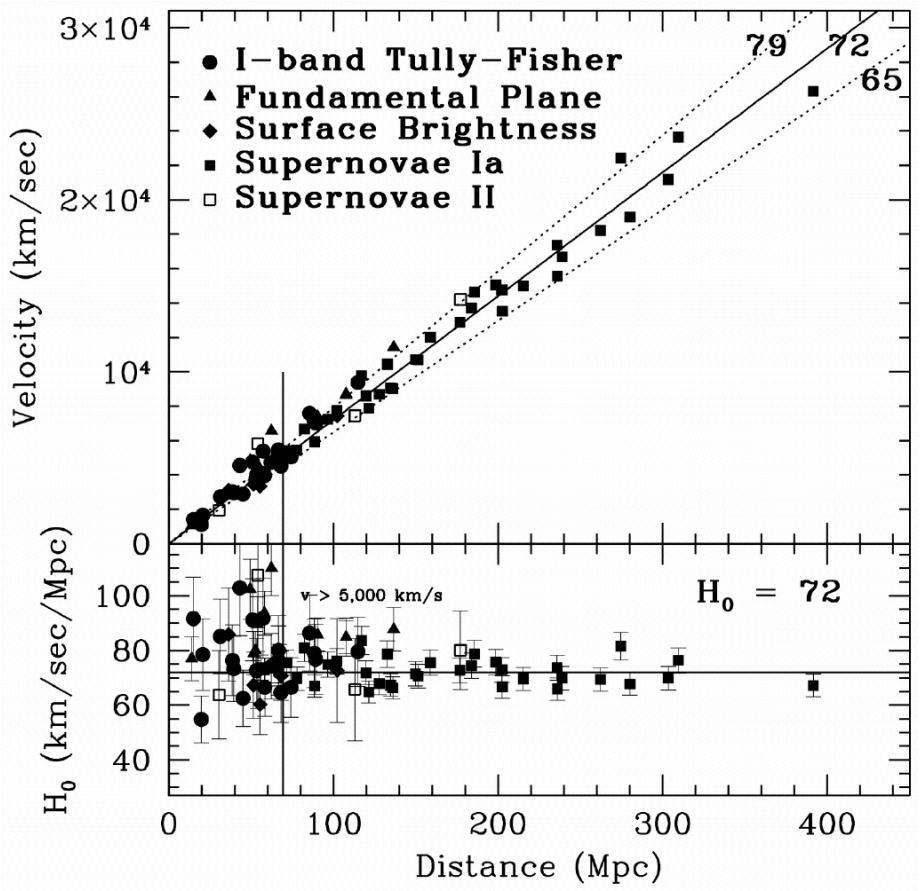
This was very astonishing since both teams basically had used the same datasets for their respective determinations of the Hubble constant

HST Key Project on Extragalactic Distance Scale

The goal was to provide H_0 determination with a precision of 10%

Freedman et al. 2001: $H_0 = 72 \pm 8$ km/s/Mpc



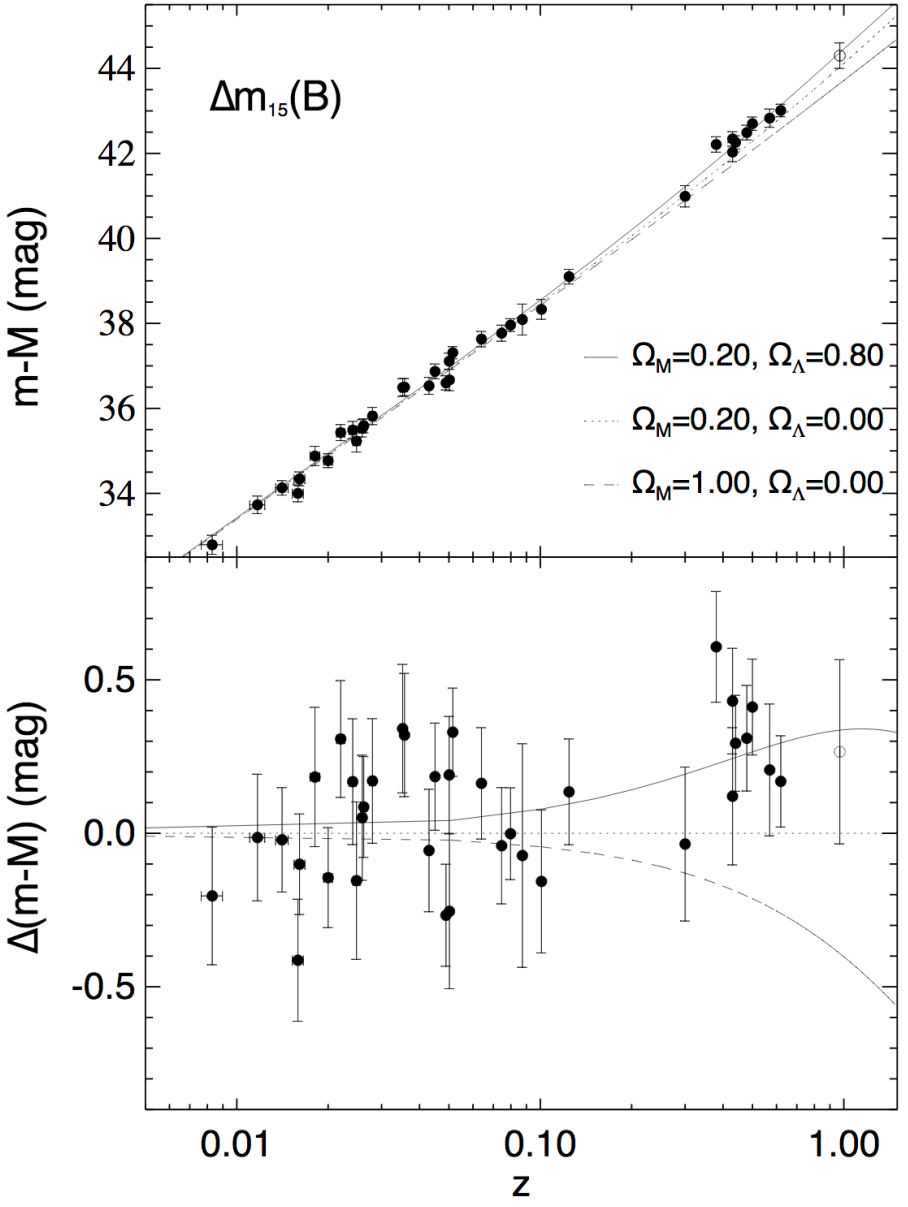


Accelerating Universe

Supernova Cosmology Project

High-Z Supernova Search Team

Noble prize 2011



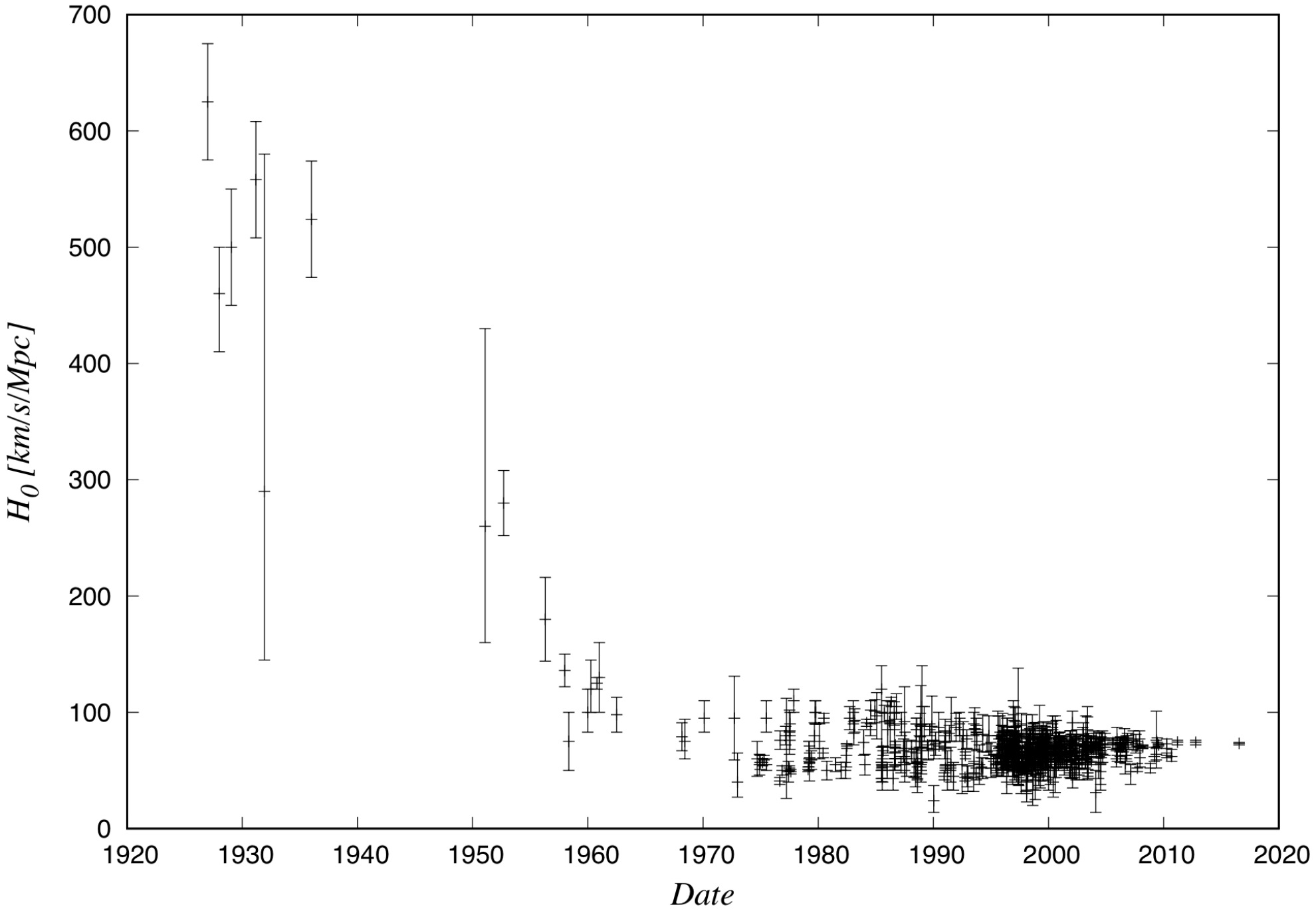
H_0 controversy

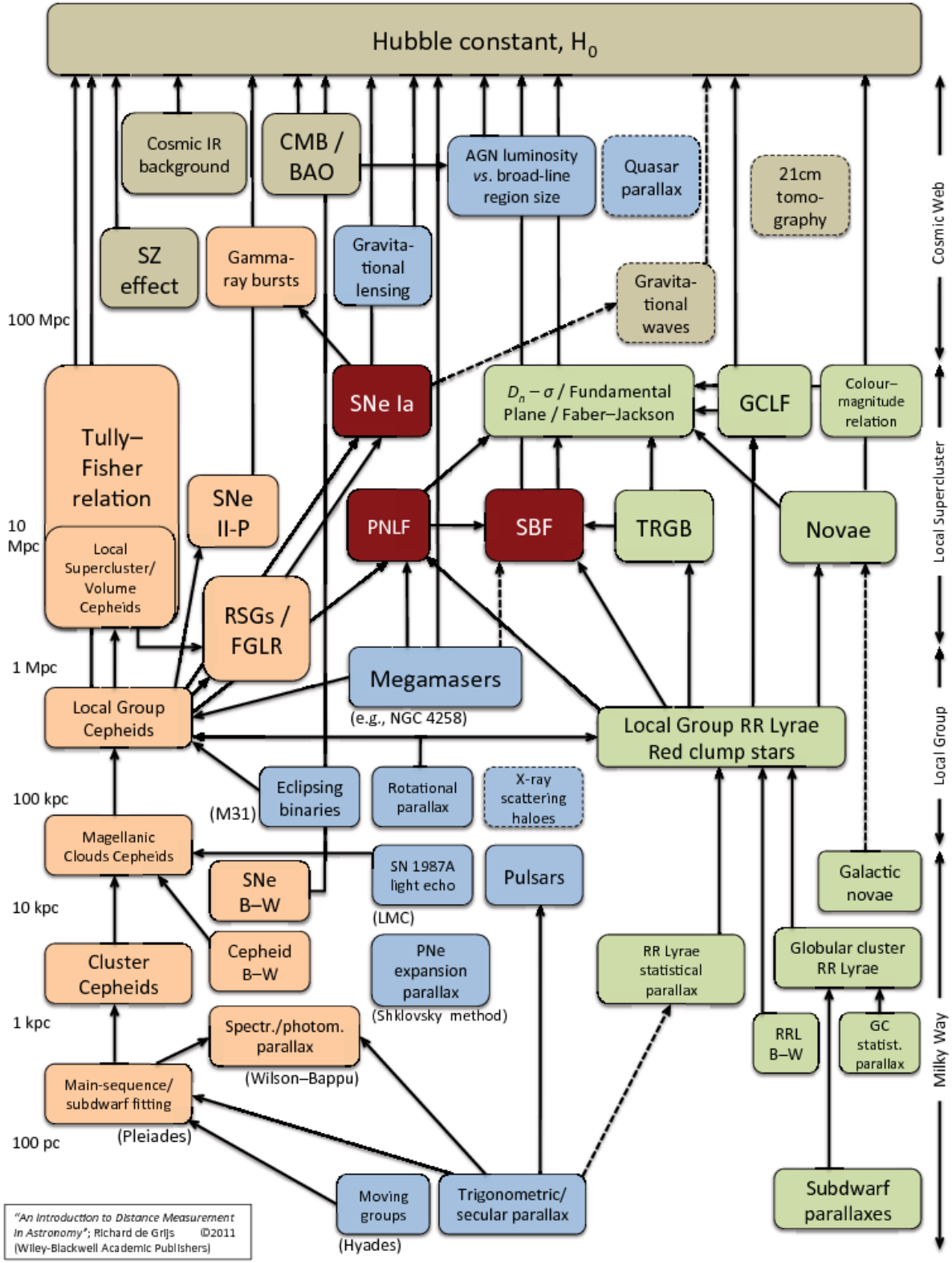
Cepheid / SN Ia: $H_0 = 74 \pm 1.42$ km/s/Mpc

Based on a ΛCDM model and the Planck CMB data $H_0 = 66.93 \pm 0.62$ km/s/Mpc.

So we have another controversy (crisis!) and modern physics might require revision ...

H_0 classical determination is extremely important again ! But we need 1% precision and ... **accuracy !**

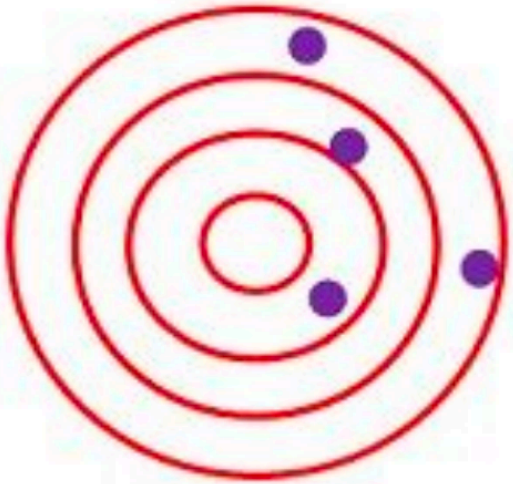

700
600
500
400
300
200
100
0
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
H_0 [km/s/Mpc]
Date


Hubble constant, H_0
Cosmic IR background
CMB / BAO
AGN luminosity *vs.* broad-line region size
Quasar parallax
21cm tomo-graphy
SZ effect
Gamma-ray bursts
Gravita-tional lensing
Gravita-tional waves
100 Mpc
SNe Ia
$D_n - \sigma$ / Fundamental Plane / Faber–Jackson
GCLF
Colour–magnitude relation
Tully–Fisher relation
SNe II-P
PNLF
SBF
TRGB
Novae
10 Mpc
Local Supercluster/ Volume Cepheids
RSGs / FGLR
1 Mpc
Megamasers
(e.g., NGC 4258)
Local Group Cepheids
Local Group RR Lyrae Red clump stars
100 kpc
(M31)
Eclipsing binaries
Rotational parallax
X-ray scattering haloes
Magellanic Clouds Cepheids
SN 1987A light echo
Pulsars
Galactic novae
SNe B–W
(LMC)
10 kpc
Cepheid B–W
PNe expansion parallax
(Shklovsky method)
RR Lyrae statistical parallax
Globular cluster RR Lyrae
Cluster Cepheids
1 kpc
Spectr./photom. parallax
(Wilson–Bappu)
RRL B–W
GC statist. parallax
Main-sequence/ subdwarf fitting
(Pleiades)
100 pc
Moving groups
(Hyades)
Trigonometric/ secular parallax
Subdwarf parallaxes
Cosmic Web
Local Supercluster
Local Group
Milky Way
"An Introduction to Distance Measurement In Astronomy"; Richard de Grijs ©2011 (Wiley-Blackwell Academic Publishers)

Accurate
and Precise

Not Accurate
but Precise

Accurate but
not Precise



Not Accurate
Not Precise

Measure vs determine

$$(m - M)_0 = 5 \times \log(d) - 5$$

$$(m\text{-}M)_0 = (m - M) - R_\lambda \times E(B\text{-}V)$$

- We need to correct for reddening assume reddenig law
- to establish M_λ one needs independent distances or to do some asumptions (models)

Therefore in astronomy in general we do not „measure" distances

Sometimes we use „measure" in the case of geometrical methods ...

But even to determine parallaxes one needs to model ...

Systematic !

All distance determinations are dominated by systematic and in most cases unknown errors.

=> LMC distances

=> Problem with the distance to Pleiades

=> H_0 determinations

The only way to control (and prove) systematic is to use different and independent techniques.